Components for Chemical Micropropulsion Systems, an overview on strategies, concepts, studies, prototypes and concrete possibilities.

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Satellites are of fundamental importance to sustain and improve the quality of life of the mankind,

Many application of satellites, like communication, environmental pollution monitoring, the road traffic control, telemedicine and Earth Sciences can be improved by means of constellation of satellites, miniaturized, serial produced and therefore cheaper. The first attempt in this direction is represented by nano and microsatellites which today are studied and prototyped worldwide for demonstration purposes.

Micro spacecrafts are presently launched as “piggy-back” payloads. In most cases it is not possible to reach a specific orbit and therefore the spacecraft must have a propulsion capability to reach its destination. Formation flying and de-orbiting will be also performed more often and therefore a path controlled by means of a certain propulsion system will be required in many cases.

Impulsive orbit manoeuvres can be performed by means of solid or fluid propulsion systems. High thrust to weight manovers such as plane inclination changes and orbit transfer are desirable for micro spacecrafts but are so far not achievable with micro-propulsion systems.

The availability of electric power in a micro-spacecraft can have an impact on the selection of the propulsion system. For primary propulsion, the payload is usually inactive and thus a large amount of spacecraft power is available for electric propulsion. However, during secondary propulsion the payload is normally active, reducing the power availability. In addition, small spacecrafts do not have high power available since the surface to volume ratio is reducing by reducing the spacecraft size. Furthermore, electrical propulsion systems could require in some cases relatively high voltage with related electronic systems which can have too higher volume.

In these scenarios a miniaturised non-electric propulsion system need to be employed.

As alternative to electric propulsion, a chemical micropropulsion system does not differs conceptually too much from a standard size propulsion system. New paradigms, offered by the miniaturisation according to scaling effects and the use of nano and microsystem technology, must be considered to get the best advantages from the miniaturisation.

ESA is well aware of these needs and a roadmap has been commonly agreed to define the steps necessary to develop a highly efficient micropropulsion system.

The activities presented in this paper forms the fundamental axis of the ESA Micropropulsion Roadmap (TOS-MPC/2168/ML), as it is shown in the figure 1.

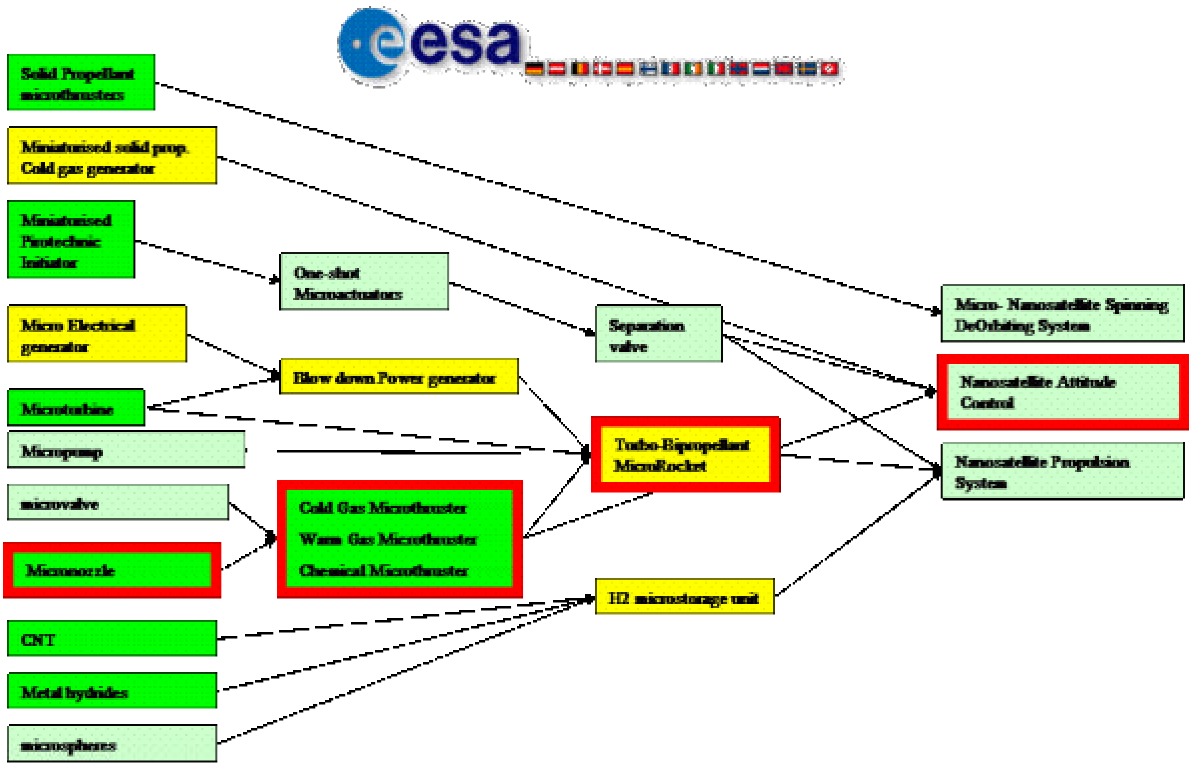

Fig.1 – ESA micropropulsion roadmap.

Small spacrafts requires also an attitude control system (ACS) which can be combined with the micropropulsion system in order to optimise the amount of components and to obtain a simple architecture. The concept proposed here, and depicted in figure 2, uses the same oxidizer of the micropropulsion, to generate the hot gases for the ACS microthrusters.

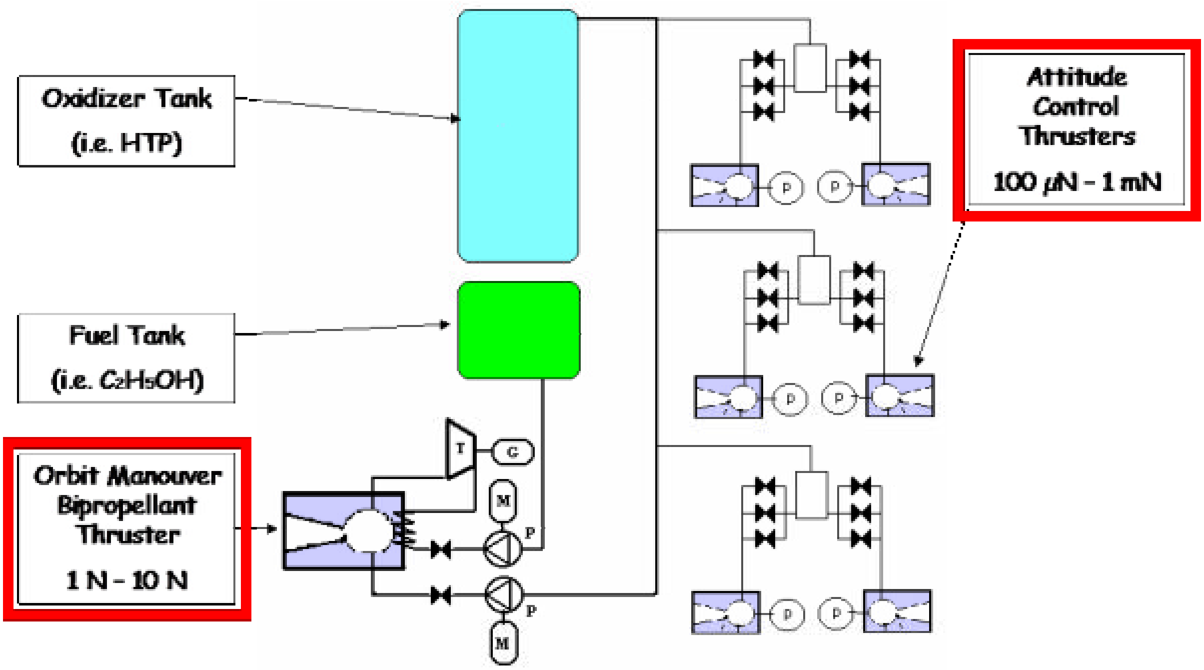

Fig.2 – Micropropulsion concept

The two systems for Attitude Control (ACS) and for Propulsion are integrated using the same propellants. This solution minimizes the number of components and simplifies the system giving also higher efficiency to the attitude control system. The selection of propellants must consider a trade-off between simplicity of usage, low cost, minimised logistic effort and performances. This means in practice the tendency to use "green-propellant" and the choice, as shown in the figure 4, has gone to the combination Hydrogen Peroxide (HTP) – Ethanol, where the HTP can be used as monopropellant also in the ACS.

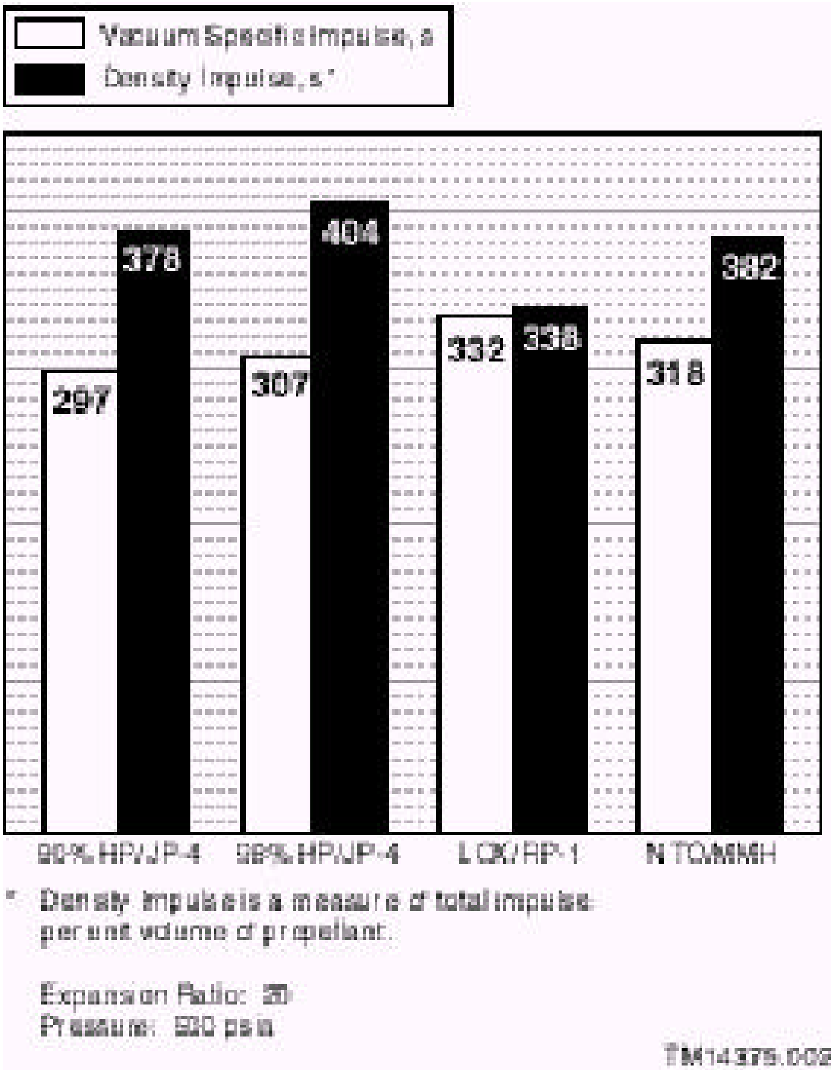

Fig.3 – Specific Impulse Comparison

One of the first steps is the realisation of a cold-gas system. Many approaches are possible, according to the available technology and funding. We believe that a highly integrated system, even if very attractive, is not compatible with the small budget available and with the need to provide the final users with a ready solution. Therefore, we concentrated on the heart of the system, the only part which really generate thrust: the micronozzle. The rest of the system can be realised by means of COTS and a clever use of available technology for the assembly.

A cold-gas microthruster on silicon, capable of 100µN to 1000µN with a Specific Impulse of 50s has been developed and tested and is in course of modification in order to achieve higher specific impulse and a more compact integration, still at hybrid level, of all the components.

The figure 3 shows some views and details of the cold-gas microthruster which has already been described in previous meetings.

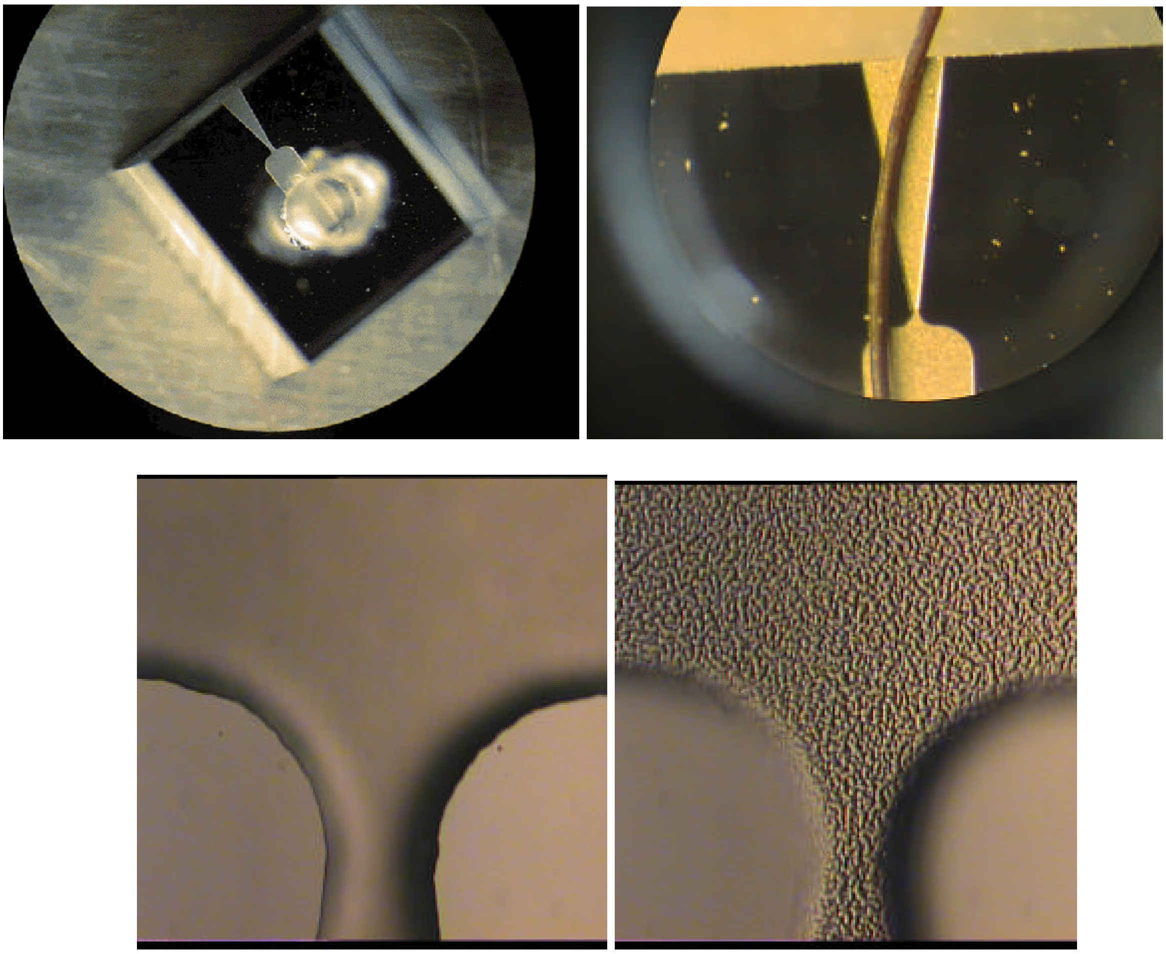

Fig. 4 – Assembly and Details of the Cold-Gas Microthruster

The design of ACS for nanosatellites, done in collaboration with the University of Bologna, has shown that a good architecture requires groups of 3 microthrusters on the corners of the satellite, therefore a particular arrangement has been studied to have a very compact group, which will be easily and modularly assembled to the satellite structure.

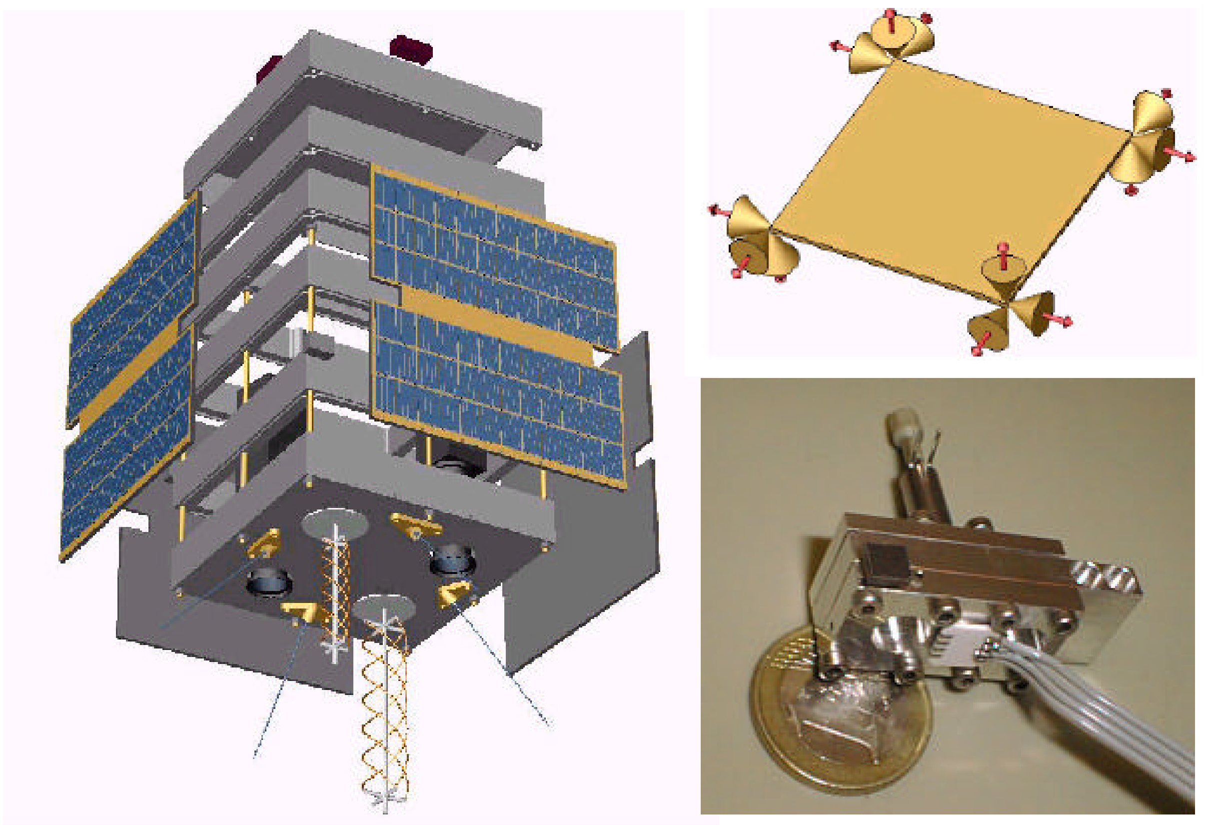

Fig. 5 – The Univerisity of Bologna AlMaSat (Alma Mater Satellite) Spacecraft

From this experience, the development of a bipropellant microrocket is already started under the ESA contract n° 16914, through the study of the mission requirements, the understanding of the benefits of miniaturisation and the design of the first building blocks. The possibility to reach the highest temperatures will be explored by means of ceramic combustion chamber for mono and bipropellant solutions. In order to get the best flexibility and to thermally decouple the components, a turbine-electrical generator has been developed to supply the micromotors that will drive the pumps. The basic sketch of the system and the first photos of the electrical generator used in the first experimental configuration are shown in the figure 6, the electrical generator is a commercial micromotor used in reverse mode.
The figure 6 shows two microturbines, one in aluminium, realised by means of high precision milling, of 10 mm external diameter, the other in nickel, of 4 mm diameter realised by LIGA nanotechnology. The LIGA microturbine is in course of development, the photo represents the PMMA mould. The photo also shows the assembly of the microturbine with the electrical generator.

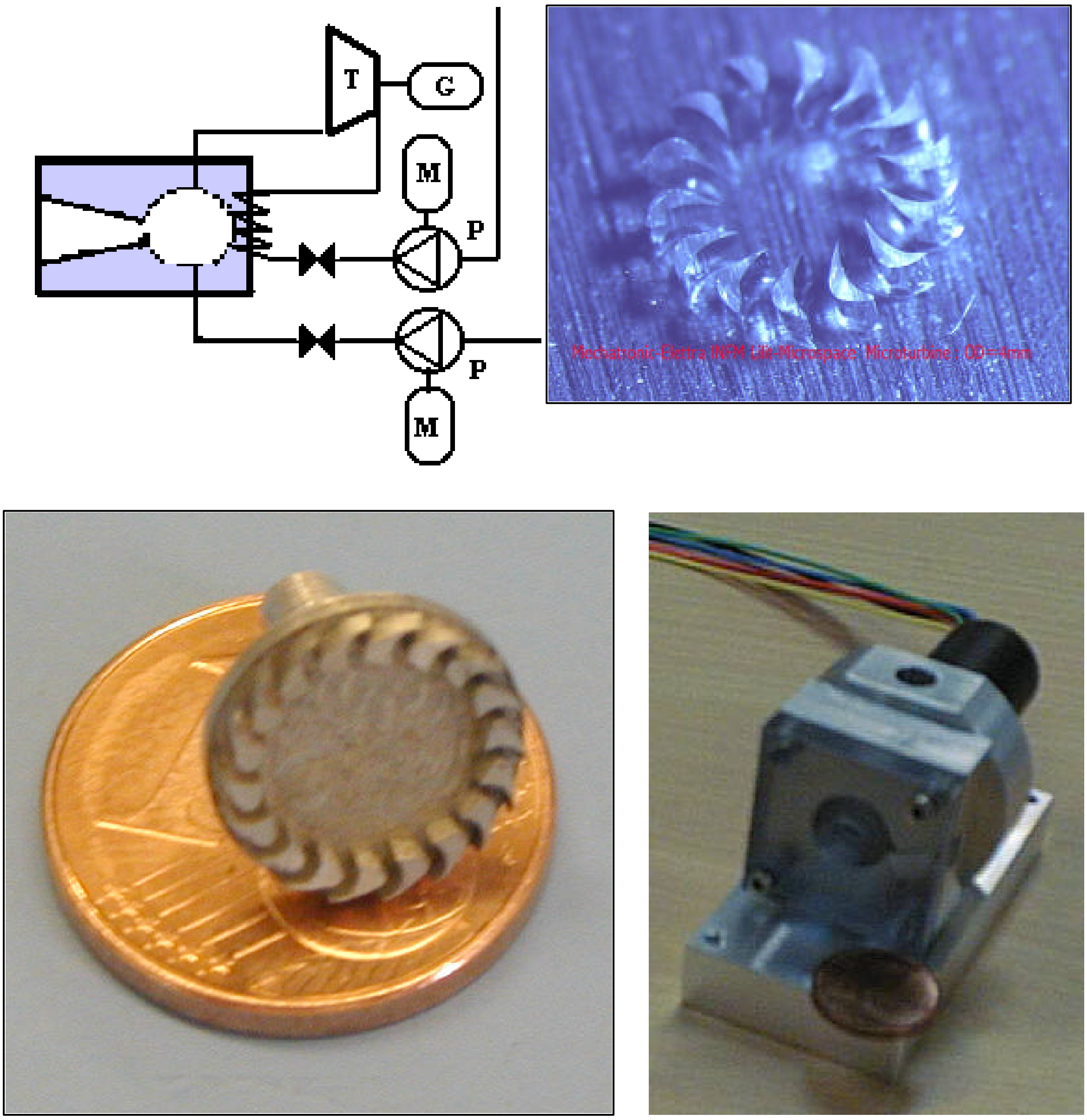

Fig. 6 – Turbo-Bipropellant Microrocket Engine Sketch and first components prototypes

The possibility to obtain few Watts from a turbine of 10 mm of diameter has been demonstrated.

The electrical connection scheme has some advantages in comparison with the mechanical connection. First of all, it can be used also as power generator for other electrical devices in micro-satellite and allow an electrical power surplus to be stored in batteries. Secondly, the transient initial phase would be more reliable because the micro-pumps can be driven previous the beginning of the combustion. Moreover, if the micro-pumps were driven directly by the micro-turbine the propellants tanks would have to be pressurised up to a certain level in order to feed the system and overcome the pressure drops from the tanks to the combustion chamber. This system would in any case require a certain time for the stabilisation of the conditions in the overall system. In addition, it allows a better control on the cycle parameters such as the feed pressure in the combustion chamber and in turn the produced thrust. A third advantage is a concern of thermal conduction in the micro-scale devices. In fact, the heating of propellants before the pumps or during the compression has to be avoided to prevent cavitations and to maintain at the lowest level the required work by the micro-pumps. In fact, the heating produces an increase in the propellant temperature and this in turn decreases the density. Therefore to reach the same compression level, the micro-pumps would produce an higher work decreasing the efficiency of the system. Again, cavitations would produce an instable flow and would damage the pump impellers in a short time due to shocks and vibrations. The use of micro-generator and electrical micro-motors would allow also a modular building of the micro-rocket engine where the only connections between different modules would be only electrical leads and fluid connections, without any moving mechanical parts. Moreover, the use of hydrogen peroxide as oxidizer and micro-motors to drive the micro-pumps has the increased possibility of using the bipropellant also as monopropellant propulsion. In fact, if the fuel line was switched off, the electrical energy stored in satellite batteries could supply the micro-motor for the hydrogen peroxide. The engine therefore would work as a normal hydrogen peroxide monopropellant.

Along the propellant feed line there is an important component for the reliability of the system: the Normally Closed Valve which will be opened when the satellite is in orbit ready for operation. This valve, normally a pyrotechnic one can also be miniaturized. For this purpose several solutions are possible, one of the solution, suitable for medium-small mass flow rates, can make use of the same principle of the standard valves (pipe cutting by means of an anvil) and of a Miniaturized Pyrotechnic Initiator (MPI) like the one we developed in the ESA contract n. 14679. A survey of the possible applications of miniaturised pyrotechnics has been fulfilled and several energy levels have been identified for the miniaturisation of the pyrotechnic devices.

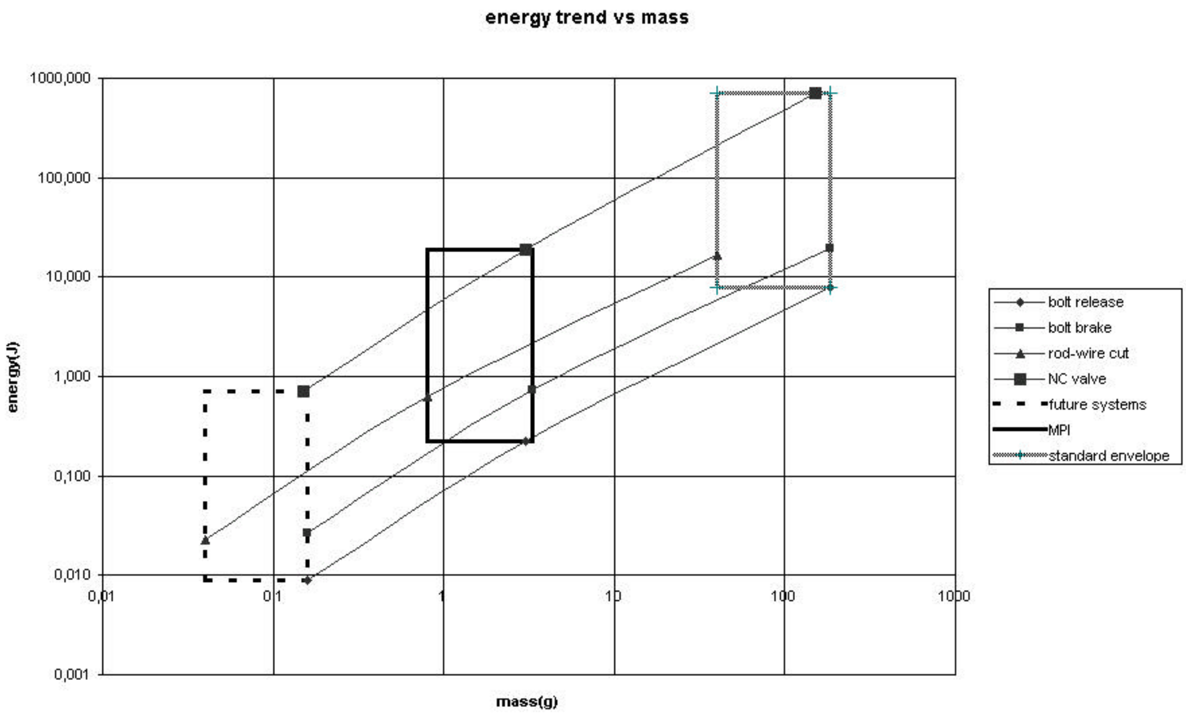

fig. 7 – Pyro Energy Levels

From the comparison between the possible needs and application and the available technologies, it appears that two levels of miniaturization are possible, a first one which consist in a standardised initiator, to be integrated in many devices like microvalves or disconnectors, a second level where the pyrotechnic charge should be directly included in the device requiring higher integration capability. Due to the limited resources available for the project it has been decided to approach only the first level and therefore the charge amount has been reduced from the 40 mg of the ESA Standard Initiator to 1-3 mg. As shown in the figure 8 a reduction of 1 order of magnitude has been achieved for the demonstrator prototypes.

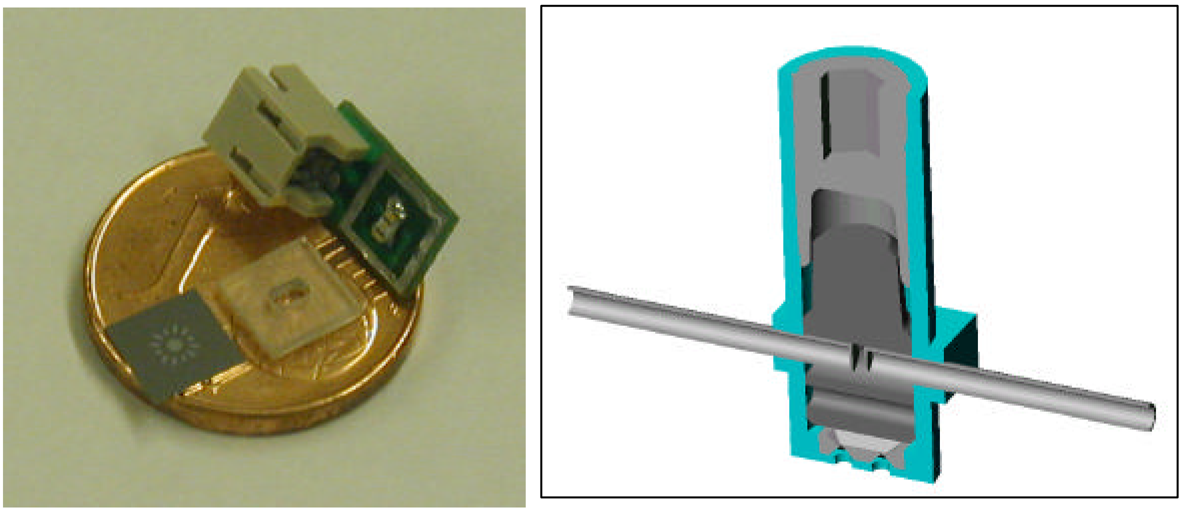

Fig. 8 – Miniaturized Pyrotechnic Initiator (MPI) and Micro Pyro-Valve based on MPI

In conclusion, the activity of micropropulsion development requires the study of many subgroups and components, the designer and the project leader must have great flexibility and wide view in order to decide which level of priority to give to any component, what must be studied first and in details and what can be adapted from commercially available componets. This approach allows to proceed along the difficult path, already traced, even with the limited budget available, still with a reasonable confidence to reach the target.